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Regards

Dossier

Dossier « À propos des relations natures/sociétés »

The shift toward social-ecological systems perspectives: insights into the human-nature relationship

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Keywords: social-ecological systems; complex systems science; resilience; transdisciplinarity; ontology of science

Abstract – This study examines how social and natural scientists converged on a new ontological approach to science. Three distinguishing features comprise this new approach. They include: (1) an integration of the social and ecological into a fully coupled social-ecological systems perspective, (2) a holistic view of scientific phenomena requiring a transdisciplinary approach to its study, and (3) the refutation of a purely equilibrium-based understanding of systems. We explore this by first introducing complex adaptive systems science and reconsidering systems theory. We next look at the application of complex adaptive systems in institutional analyses conducted by political economists. Following this, we show how ecologists used the concept of resilience to apply a similar approach to the study of ecosystems. Finally, we show how a growing community of social and natural scientists have united to utilize a social-ecological systems framework to take a more holistic and transdisciplinary approach to science.

Mots-clés : systèmes socioécologiques ; science des systèmes complexes ; résilience ; transdisciplinarité ; ontologie de la science

Résumé – Pour une approche des relations homme-nature : évolution et perspectives de la notion des systèmes socioécologiques. Cette étude examine comment des chercheurs en sciences sociales et en sciences de la nature ont convergé vers une nouvelle ontologie scientifique. Trois éléments distincts composent cette nouvelle approche : (1) une intégration du social et de l'écologique dans la perspective d'un véritable couplage socioécologique des systèmes ; (2) une vue holistique des phénomènes scientifiques nécessitant une démarche transdisciplinaire ; et (3) la réfutation d'une vision des systèmes en équilibre stable. Nous explorons ces trois éléments en faisant appel à une science des systèmes complexes adaptatifs, et en reconsidérant la théorie des systèmes. Nous examinons ensuite l'application des systèmes complexes adaptatifs aux analyses institutionnelles conduites par les économistes politiques. Ce faisant, nous montrons comment des écologues utilisent le concept de résilience dans une approche similaire pour étudier les écosystèmes. Finalement, nous analysons comment une communauté croissante de chercheurs en sciences sociales et en sciences de la nature s'est fédérée pour utiliser le cadre conceptuel des systèmes socioécologiques pour mettre en place une démarche scientifique plus transdisciplinaire et holistique.

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Voir, dans ce même numéro, les autres contributions au dossier « À propos des relations natures/sociétés » : le texte d'introduction de Xavier Arnauld de Sartre, Bernard Hubert et François Bousquet, le texte de Thomas J. Bassett et Alex W. Peimer et le texte de Patrick Caron.

Introduction

Over the past twenty-five years science has witnessed an ontological shift in understanding human-nature relationships. Variously called coupled natural-human systems, coupled human-environment systems, socio-environmental systems or social-ecological systems (as referred to in this article), all refer to a backlash against three features prevalent in past scientific studies. First, a strong version of social-ecological systems (SES) represent a re-integration of thinking about, analyzing and studying humans as an integral part of the biophysical world. Nature no longer simply sets the context in which social interactions take place. Likewise, the human enterprise is not an external disturbance acting upon an ecosystem. Both strong and weak versions of SES focus on the interactive interactions and feedbacks between the social and ecological. This coupling, however, goes further than simply discussing both as separate but equal systems. Rather, the variables analyzed, theories for understanding, and methods for studying SES all require revisiting. Second, studies of SES have increasingly focused on interdisciplinarity as a scientific approach. The linkage of social and ecological systems requires moving beyond bringing disciplinary experts (multidisciplinarity) together and requires transdisciplinary methodologies. In doing so, such approaches have also changed scientific perspectives from narrow, reductionist views to a more holistic type of questioning and problem-solving. Third, and most importantly, SES approaches moved away from the past traditional equilibrium-based models of disciplines such as economics and ecology and toward a more fluid, dynamic, non-equilibrium based analysis.

This article draws on the historical convergence of scientists from three fields – ecology, economics, and physics – toward a social-ecological system approach. The encounter of these three fields has led in unexpected directions under the banner of complex adaptive systems and resilience. This article tracks this trajectory from the individual disciplines to their integration around the concept of social-ecological systems. It begins with a systems view of science. It then looks at how complex adaptive systems studies, ecological applications of resilience, and political economy approaches to institutional analysis, all converged on social-ecological systems as a new ontological approach to science.

A systems approach and introduction to complexity

Before discussing further what is meant by social-ecological systems, we need to decide (1) what we mean by systems, and (2) what we mean when we talk about complexity. Our intent is not to provide an in-depth study of these concepts but to provide a cursory overview, as needed to understand linked SES. For these purposes, we can identify a system as referring to an "integrated whole" and being constituted of several interacting parts or elements. Of course, this presupposes the presence of a boundary delineating which parts (or units or elements) are inside the system and which are outside of it. The scientist specifies these boundaries in an attempt to adroitly analyze and address specific research questions. This also means that scientists studying related phenomena might choose quite different system delineations. For our purposes, the system should be socially and ecologically coterminous. Systems may be said to share common characteristics, including: (1) a dynamic structure, which may be defined by components and their composition; (2) behavior, which involves processing inputs and generating outputs; and (3) interconnectivity in that the various parts of a system have functional as well as structural relationships among one another. Many systems may also be selected or identified by a shared functionality or purpose (e.g. a digestive system or an economic system). Often, systems may be viewed as being nested and interlinked with other systems. In such a manner, analysis may occur at multiple levels or scales and can relate to "externalities" beyond the system under study.

Complexity generally refers to the study of how large-scale complex, organized, and adaptive behavior can emerge from (relatively) simple interactions among myriad individuals (Prigogine, 1980; Mitchell, 2009). Building on the systems approach above, Weaver (1948) identifies systems of organized complexity in which many components interact in ways that lead to outcomes qualitatively different from the simple summation of the individual interactions. This has been referred to in classical texts as "More is different" (Anderson, 1972), transitioning from quantity to quality (Carneiro, 2000), or emergence (Holland, 1999). More specifically, scientists define a complex adaptive system as comprised of many components that dynamically interact at a micro level. As a result of these interactions, a heterogeneous and diverse network of such interacting, independent actors forms itself, which learns and adapts over time. The behavior of a complex system is generally said to be emergent – behavior that cannot be inferred from the behavior of its components – and subject to self-organization so that some form of aggregated or global order emerges from uncoordinated local interactions. In short, the macro-level behavior or pattern of the system is more than the sum of the micro-level behaviors of its components. Finally, complex adaptive systems are generally seen to be nested like Russian matryoshka dolls with broader and narrower scale interactions that influence and affect actors and phenomena at other scales.

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Complex adaptive systems: reconsidering systems theory

Some of the basic ideas of complex systems thinking have been around for a long time (Ferguson, 1767; Hayek, 1978), but the Complex Systems movement crystallized in the mid-1980's both in Europe (around the chemist Ilya Prigogine) and in the US (around the physicist Murray Gell-Mann and the Santa Fe Institute), who both realized that rather complex system interactions, with hitherto unpredictable outcomes, could in effect be summarized in simple sets of equations[1]. Under the impetus of the Santa Fe Institute and a growing community of scientists worldwide, the approach spread in the natural sciences, biology (Rosen, 1985, 1991), ecology (Levin, 1998, 2000) economics (e.g. Colander, 2000), organization and management science (Schneider and Somers, 2006; Dooley, 1997; Choi *et al.*, 2001), engineering and the social sciences (e.g. Lansing, 2003; Miller and Page, 2009).

In the process, a number of assumptions of the extant "reductionist" approach were revised. Some of these differences are, in no particular order (1) the reversal of Occam's razor – instead of choosing the simplest from among a range of different explanations, one might want to favor the more complex ones, (2) the assumption that highly similar (if not indistinguishable) initial circumstances might over time lead to very different phenomena, or vice-versa, that very different initial circumstances might lead to very similar phenomena, thus undermining our traditional idea of cause-and-effect, (3) the idea that all systems should be treated as open systems that are permanently undergoing change (summarized by Prigogine in his 1980 book title as *From being to becoming*), so that the assumption of "equilibrium" needs to be replaced by a very different kind of understanding, in which the history of the system plays a major role. Such complex systems (4) evolve by a history of irreversible and unexpected events, which Gell-Mann calls "an accumulation of frozen accidents", in which both process and event play a role (see also Monod, 1971). This leads to the assumption that (5) the trajectories of such systems are fundamentally unpredictable, a phenomenon that one could call their "ontological uncertainty" (Lane and Maxfield, 2004; Langton, 1992). Other important characteristics are the fact that this approach (6) focuses on relationships, and in particular networks of such relationships (Watts, 1999; Amarral and Ottino, 2004; Newman, 2010) and that (7) it substitutes an "ex ante" perspective (study of emergence, prediction) for the traditional "ex post" perspective (the study of origins, explanation) of the reductionist approach (van der Leeuw *et al.*, 2011). In so far as it concerns the study of socio-environmental systems (8) it has to some extent moved from modeling by means of differential equations (or the more complex Master equation) towards agent-based modeling. And finally the approach is (9) characterized since its earliest days by attempts at holistic intellectual fusion across disciplines, inherent in the assumption that at any time a wide range of dynamics can impact on the system concerned.

From the perspective of this paper, what seems particularly interesting is how the contribution of the natural sciences has been integrated in the wider field of sustainability studies with a combination of social anthropology, which has contributed "Cultural Theory" (Thompson *et al.*, 1990), the sciences of organization and information, which have contributed to our understanding of the organization dynamics of social structures (*e.g.* Pattee, 1973; Simon, 1969; Huberman, 1988) that have been taken up and adapted in turn by ecologists (*e.g.* Allen and Starr, 1982; O'Neill *et al.*, 1986; Allen and Hoekstra, 1992), leading to a first attempt at synthesis of these different ideas by a collaborative effort of ecologists and social scientists (Gunderson and Holling, 2002; Holling, 2001; Walker and Salt, 2006). In that process, Luhmann, Ostrom, Holling, Levin and Folke stand out as the giants upon whose shoulders we are currently standing.

Forming a new field: the emergence of social-ecological systems

Scientific research on social-ecological systems has grown exponentially over the past two decades from a base of nearly nothing in the 1970s and 1980s (30 citations in 1970, 183 in 1980 and 373 in 1990) to current citations in the literature of over 14,000 in 2013 (Fig. 1 – citation rates from Google Scholar accessed August 15, 2014).

We argue that this is due to a unique concatenation of events in the late 1990s and early 2000s in which the fields of political economics (institutional analysis), ecology (through resilience), and complexity science converged and coalesced, leading to outcomes that moved us in unexpected directions. Leading scholars in each of these fields grew increasingly frustrated with traditional approaches and methods that decoupled social and ecological systems and focused on equilibrium dynamics. In all three cases, therefore, researchers brought together multiple disciplines to grapple with research questions and phenomena that went beyond the traditional training in any individual field. The research required going beyond classic multidisciplinary approaches that juxtaposed different disciplines to achieve tighter integration and blending into transdisciplinary research (Max-Neef, 2005) or "intellectual fusion" (Crow, 2010). Additionally,

[1] A good introduction to the approach, and to some of the history of it, is Mitchell (2009).

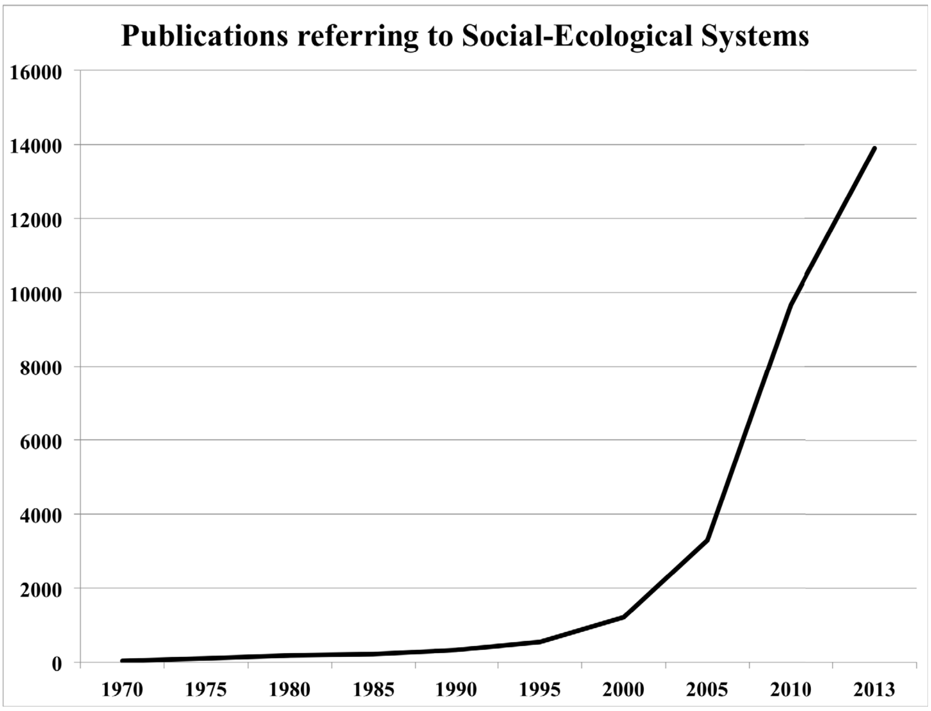

Fig. 1. Growth in the study of social-scological systems (Schoon and van der Leeuw, 2015).

in each case, it required researchers to realize that an epistemologically new approach was needed beyond traditional equilibrium models. This new approach, emerging from complex systems science, demonstrated that living, open systems are generally not in equilibrium and that closed equilibrium systems are essentially "dead", so that studying external disturbances of such systems is not a fruitful way to gain understanding of such phenomena. In what follows, we track how work on the political economy and in ecology, following their own path dependencies, led to a linked or coupled view of human systems and the natural environment – to social-ecological systems.

Institutional analysis: a new approach to political economy

In the 1980s, political economist Elinor Ostrom began shifting more of her research toward the study of common-pool resources and grappling with Hardin's Tragedy of the Commons (1968). In doing so, she focused efforts on small-scale, community-based natural resource management. In particular, the research examined instances of self-governance that resolved (or failed to) Hardin's tragedy. A critically important part of this research was how the combination of contextual variables influenced what Ostrom calls an action arena (Ostrom *et al.*, 1994). The action arena is where multiple actors – individuals and formally or informally organized groups of people – interact and lead to outcomes, whether social, ecological or social-ecological (Ostrom, 1999). These interactions serve as the building blocks for understanding how institutions and people co-produce outcomes, in this case the appropriation and governance of natural resources, and serve as the foundation of the Institutional Analysis and Development (IAD) Framework (Fig. 2).

In creating the IAD Framework, institutional scholars focused a great deal on the exogenous variables – grouped as the biophysical conditions, the attributes of community, and the rules-in-use. Initial studies focused on specific subsets of these variables, but as scholars worked more with the IAD the integration of the ecological, social, and institutional environments played an increasingly large role in understanding how different combinations of variables influenced outcomes. As the number of potential variables continued to increase, Ostrom and others built databases for two major, ongoing research initiatives – the Common-Pool Resource (CPR) database and the International Forestry Resources and Institutions (IFRI) project (Ostrom, 1998). The challenge remained how to grapple with causality with so many potentially confounding variables.

As Ostrom struggled with these challenges, she began to use game theory and lab experimentation in her work (Ostrom, 1990). Similarly, other social scientists were also drawing on game theory and computer modeling. Using

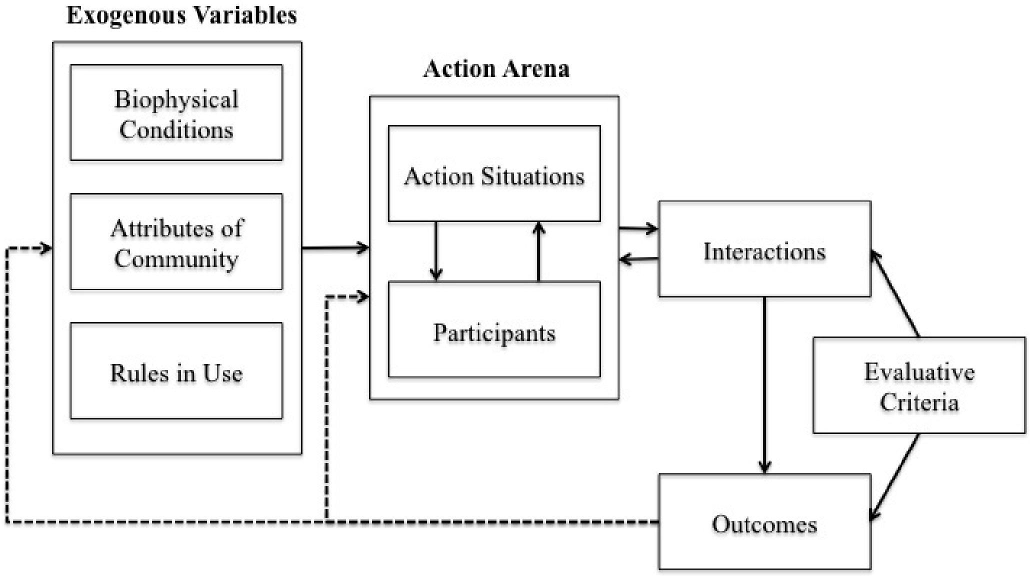

Fig. 2. The Institutional Analysis and Development (IAD) Framework (Schoon, 2015 after Ostrom *et al.*, 1994, p. 37).

these approaches, Robert Axelrod first brought complex systems into the social sciences. In his classic "Evolution of Cooperation" tournament, he and others explored how groups of people could interact and learn to work together (Axelrod, 1984). In 1993, the Beijer Institute of Ecological Economics began their Askö workshops, bringing together leading ecologists and social scientists (Söderqvist *et al.*, 2011). These meetings focused on the challenges of sustainability and addressed a given topic every year, ranging from food production and population growth in one year to the valuation of nature in the following year. The broader focus, set at the initial meeting, was the integration of social and ecological science and scientists. In Ostrom's research, by the early 2000s, the contextual variables of the IAD framework became more and more tightly intertwined with a coupled systems perspective (Committee on the Human Dimensions of Global Change *et al.*, 2002).

In the 1990s, Ostrom's study of common-pool resources started building upon linkages with ecologists, in particular with resilience scientists, principally ecologists, who provided a mirror image to the anthropologists, economists, and political scientists engaged in research on the commons, as natural scientists heavily influenced by findings from social sciences. Following these interactions, Ostrom embarked on a new approach to the study of what she began calling "complex social-ecological systems" – a diagnostic approach that helped identify the key variables that could affect the probability of long-term sustainability of such systems and allow for cross-case comparisons (Ostrom, 2009). She called this the Social-Ecological Systems Framework (Ostrom, 2007). One of the challenges that Ostrom confronted in both the IAD Framework and the SES Framework required bridging the divide between the boundedly rational approaches of economics with the (much wider and more encompassing) cultural dimensions of anthropology to gain new knowledge about decision-making.

Resilience: redefining ecology

While Ostrom was leading a movement toward complex adaptive systems and linking social and ecological sub-systems in political economic studies of common-pool resource management, a similar trend was underway in ecology. C.S. ("Buzz") Holling's (1973) paper on resilience sparked this movement. His paper drew deeply on his original work in cybernetics and systems dynamics. In it, Holling challenged the notion that ecosystems moved toward equilibrium. Instead, he argued that ecosystems often moved between multiple stable states. He posited the notion of ecosystem resilience as the capacity of an ecosystem to tolerate disturbance without moving into a qualitatively different state that is controlled by a different set of processes.

This theoretical research was followed by empirical studies that looked at state transitions or regime shifts across a variety of ecosystems including forests-savannas (Walker *et al.*, 1981), coral reefs (Hughes *et al.*, 2003), lakes (Carpenter *et al.*, 1999), and others (Biggs *et al.*, 2009). Building on these ideas, Holling and others started to

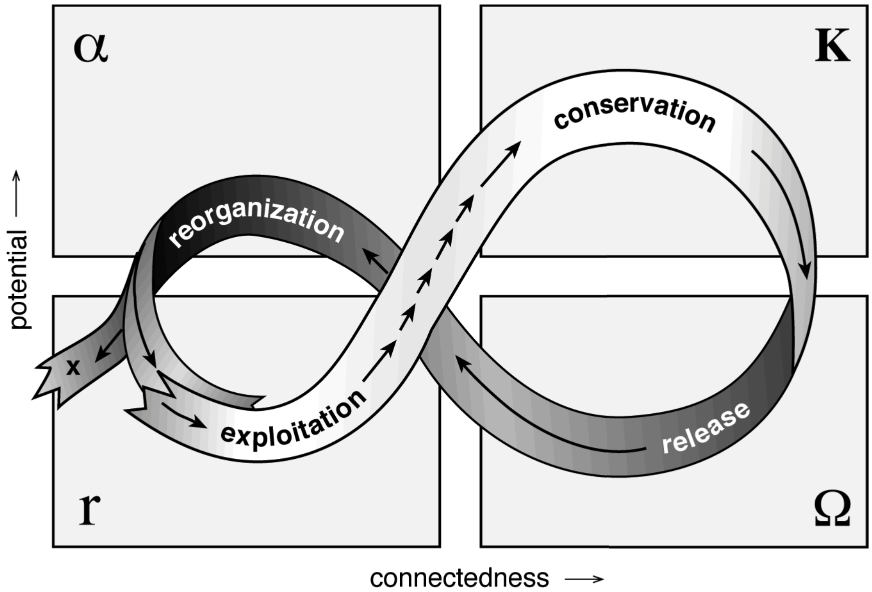

Fig. 3. The adaptive cycle (from *Panarchy*, edited by Lance H. Gunderson and C.S. Holling: Figure 2-1 (page 34). Copyright © 2002 Island Press. Reproduced by permission of Island Press, Washington, DC).

explore the ramifications for managers. These ramifications include the need for learning, adapting to a system rarely in a stable equilibrium, and an acknowledgement that system complexity makes it unclear how any management intervention will ultimately affect the system due to unexpected consequences. This led to a new approach for practitioners – adaptive management (Holling, 1978 and Walters, 1986) – in which decision-making consists of scientific experimentation and iteration in the face of uncertainty with a goal to reduce uncertainty through a scientifically based system of monitoring and modifying decisions based on measured outcomes.

Adaptive management drove a push into more explicit natural resource management issues, and further into the social system (and the social sciences) defined as a part of a broader system rather than as an ecosystem subjected to external disturbances. In one early result from this partnership of social and natural scientists, Gunderson *et al.* (1995) used case studies and complexity science to explore the interactions between ecosystems and society, making early inroads in explicitly combining the social and ecological sciences. Building on this, Berkes *et al.*, in 1998 and its follow-up text (2002), began explicitly referring to, studying, and coupling the social and ecological as "social-ecological systems", first coined by Gallopin (1991). These studies explored how a view of coupled social-ecological systems could be beneficial and help society adapt and build resilience, leading to new insights for managers striving toward sustainability. Resilience scientists continued to analyze linked SES in Gunderson and Holling (2002) which drew even more explicitly on SES as a coupled system and went back to the original roots of resilience in complexity science and Holling's cybernetics and systems dynamics work – drawing on concepts of hierarchies (Allen and Starr, 1982), decomposable systems (Simon, 1991), self-organization (Levin, 1999), and others. The principal contribution of "Panarchy" was at a theoretical level – how linked social-ecological systems travel through an adaptive cycle (Fig. 3), moving from an exploitation phase to a conservation phase and then often into a "back loop" of release and reorganization. The adaptive cycle, which many systems transition through, is in turn nested within a Panarchy of systems larger and smaller also going through adaptive cycles (Fig. 4).

Social-ecological systems and a new ontological approach to science

The convergence of social and natural scientists on a complex systems approach to science has profound implications for science in the 21st Century. Principally, this article has examined how this convergence is comprised of three differentiating characteristics – (1) a complete integration of the social and ecological into a fully coupled social-ecological systems perspective, (2) a holistic view of scientific phenomena requiring a transdisciplinary approach to its study, and (3) the refutation of a purely equilibrium-based understanding of systems. This new ontological approach to science brings with it opportunity for new breakthroughs and advances in understanding. It also creates great new challenges in

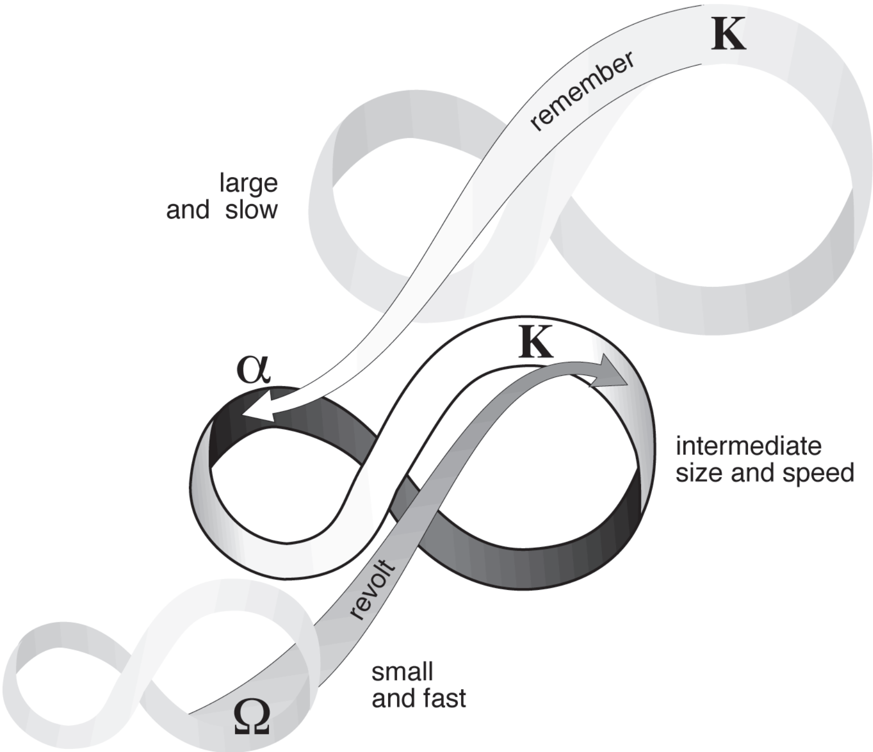

Fig. 4. Panarchy of nested adaptive cycles (from *Panarchy*, edited by Lance H. Gunderson and C.S. Holling: Figure 3-10 (page 75). Copyright © 2002 Island Press. Reproduced by permission of Island Press, Washington, DC).

science. First, advancing understanding will require theoreticians to rethink the theoretical foundations upon which to approach science. This could involve going back to the roots of emergent properties, as Ostrom's institutional analysis returned to methodological individualism – looking at social phenomena as the interaction of individuals – from which to start theorizing the role of institutions in shaping behavior (Ostrom, 1990). A continuing challenge in institutional economics is the process of shifting from the individual to the organization or population as the level of analysis (and vice-versa), in the spirit of John R. Commons (Chavance, 2012; Lane *et al.*, 2009). Another example is the theorizing behind preferential attachment as a means to explain unequal distributions (Simon, 1955). Second, it will likely require new methodological approaches. These may include new computational methods, advances in artificial intelligence, or new types of modeling building on the latest agent-based and other modeling techniques that allow for phenomenological emergence (Janssen and de Vries, 1998; Lansing and Kremer, 1994; Bousquet *et al.*, 1993). Past methods that were reliant on simple causal models will often be rejected as poor representations of reality. Methods that straightforwardly assume such relations or are overly reliant on equilibrium-based assumptions will no longer suffice to gain scientific insight. Third, the act of engagement with the scientific enterprise requires asking when it is appropriate and fruitful to take a reductionist approach and applying Occam's Razor and when to take a holistic, complexity science approach. Different questions call for different ontological approaches, and this dilemma is by no means simple or straightforward. For instance, while some engineering challenges – however complicated (e.g. the Apollo moon missions) – may involve extended calculations within a reductionist paradigm, other engineering challenges, such as trade-offs in robustness to multiple disturbances or risk mitigation in an unknown future environment, align at various points along a continuum between the effectiveness and ineffectiveness of reductionist approaches. Similar examples of pragmatic choice between predominantly reductionist and complexity-based approaches to science occur across all fields of study.

Perhaps the greatest challenge to this new ontological approach to science is about discerning good science. As Moss and Edmonds (2005) discuss, this requires rethinking how theory and data are used and the mix in which researchers draw upon deductive and inductive thinking. How one teaches, engages, and judges new science will require diligence and careful thought. Today's students in some places now graduate from transdisciplinary departments and have non-reductionist approaches to science. They draw on different theories, training, and methodological approaches than those from which their mentors and advisors started. Training students – either for the academy or for real-world work beyond the academy – will benefit from a coupled systems approach rather than past training. However, it will also require employers to appreciate the benefits and new graduates to understand how to articulate them lucidly. Likewise, reviewing and critiquing research in the future will necessitate reviewers stepping outside of clearly delineated disciplinary backgrounds, exclusive views of theorizing from past worldviews and methodological approaches. Further, it will require editors to rethink the mission of their journals in some cases and create new journals in other cases. Taking a social-ecological systems perspective has the potential to shape the scientific frontier and reshape our fundamental approach to understanding and to the scientific enterprise. It is a time for change.

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